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Effectiveness of Airboat Electrofishing for Sampling Fishes in Shallow, Vegetated Habitats

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Abstract.—We evaluated the effectiveness of airboat electrofishing for sampling large fishes (standard length, SL ≥8 cm) in shallow, vegetated habitats. Concurrent block-netting (0.1 ha) and airboat electrofishing were conducted at 11 sites in freshwater marshes of the Florida Everglades. We found significant positive relationships between log-transformed electrofishing catch per unit effort (CPUE) and both fish density (number/0.1 ha) and biomass (grams dry weight/0.1 ha) estimates from block nets. Analysis of covariance revealed that estimates of species richness were similar for electrofishing and block-net samples after accounting for differences in the total number of individuals sampled. Nevertheless, length-frequency and species-composition data differed between airboat electrofishing and block-net samples. Relative abundance of yellow bullheads *Ameiurus natalis,* Seminole killifish *Fundulus seminolis,* sunfishes (*Lepomis* spp.), and small size-classes of all species, were lower for electrofishing than for block-net samples. Florida gars *Lepisosteus platyrhincus,* largemouth bass *Micropterus salmoides,* and large size-classes of all species, had greater relative abundances in the electrofishing samples than in the block-net samples. Despite these differences, CPUE from airboat electrofishing was positively related to fish density in block nets for two size-classes (from 8 to <12 cm SL and ≥12 cm SL). Residuals from the CPUE–fish density regression were unpatterned with respect to water depth, conductivity, and floating-mat volume but were positively related to emergent-stem density. This suggests that electrofishing was less effective in sparsely vegetated habitats, possibly because fish were better able to detect and flee from the airboat. Our study suggests that airboat-electrofishing ($\log_{10}$CPUE) provides a useful index of the abundance of large fishes in shallow, vegetated habitats, but length-frequency and species-composition data should be interpreted with caution. Additionally, emergent-stem density should be included as a covariate in statistical analyses of airboat electrofishing CPUE.

Fishes are important components of freshwater communities in vegetated habitats such as marshes, swamps, and littoral zones of lakes. As consumers, fishes can influence the abundance, composition, and size structure of zooplankton, gastropods, insects, and other species in these habitats (Bronmark 1988; Mittelbach 1988; Schriver et al. 1995; Pierce and Hinrichs 1997). Fishes are also important prey for other species, and the population dynamics of some wading birds are thought to be largely dependent on the availability of prey fishes in shallow marshes (Hoffman et al. 1994; Loftus and Eklund 1994). Nevertheless, our understanding of the population dynamics and community ecology of marsh and littoral fishes has been significantly hindered by the difficulty of accurately assessing fish abundance and species composition in shallow, vegetated habitats (Chick et al. 1992; Loftus and Eklund 1994; Jordan et al. 1997; Rozas and Minello 1997).

A variety of enclosure traps have been used to sample fishes in vegetated habitats. Throw traps, usually around 1 m^2 in size, are effective for sampling fishes in a variety of vegetated habitats but are most effective for sampling fishes generally less than 8–10 cm standard length (SL) because of the small area sampled (Kushlan 1981; Jacobsen and Kushlan 1987; Chick et al. 1992; Jordan et al. 1997; Rozas and Minello 1997). Large enclosure traps, such as drop traps, pull-up nets, and buoyant pop nets have been used for sampling fishes greater than 8 cm SL, but these methods can alter habitats and their effectiveness for sampling large fishes remains questionable (Loftus and Eklund 1994; Rozas and Minello 1997). A more accepted method for estimating abundance and composition of large fishes in vegetated habitats is rotenone sampling within block nets (0.08–0.41 ha; Timmons et al. 1979; Shireman et al. 1981; Davies and Shelton 1983). The spatial and temporal extent of block-net studies, however, is often limited because this method requires substantial field effort and depletes fish from the study areas (Davies and Shelton 1983; Rozas and Minello 1997).

Electrofishing has been used successfully to sample fishes in a variety of freshwater habitats (Reynolds 1983). Boat-mounted electrofishing units are considered effective for sampling large fishes

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and can be used more frequently over larger spatial areas than block nets. Although this technique does not provide direct estimates of density or biomass per unit area, electrofishing catch per unit effort (CPUE) provides an index of fish abundance (Reynolds 1983; Burkhardt and Gutreuter 1995). Studies of populations of largemouth bass *Micropterus salmoides* and walleye *Stizostedion vitreum* have found significant relationships between electrofishing CPUE and fish density (Serns 1982, 1983; Hall 1986; McInerny and Degan 1993; Edwards et al. 1997). Electrofishing has been used to assess fish abundance and composition in vegetated habitats, but shallow water and dense vegetation can limit access of standard electrofishing boats (Killgore et al. 1989; Gelwick and Matthews 1990; Miranda and Pugh 1997). Mounting an electrofishing unit on an airboat allows this technique to be used in a greater variety of vegetated habitats, but no studies have assessed the effectiveness of airboat electrofishing in freshwater marshes.

To determine if airboat electrofishing provides a useful index of the abundance of large fishes (SL >8 cm) in freshwater marshes, we compared CPUE from airboat electrofishing with fish density estimated from 0.1-ha block nets in sloughs and wet prairies of the Florida Everglades. We assumed block nets would provided reasonably accurate estimates of the abundance, composition, and size distribution of large fishes. Because electrofishing is known to have species-specific and size-related biases, we also compared species composition and size-frequency distributions from these two methods. Finally, we examined the effects of habitat parameters—water depth, conductivity, emergent-stem density, and floating-mat volume—on electrofishing CPUE.

Methods

Study area.—Between November 1997 and February 1998, we collected concurrent block-net and electrofishing data from 11 sites in freshwater marshes of the Florida Everglades, including Water Conservation Area-2A (WCA-2A), WCA-3A, and Shark River Slough and Taylor Slough in Everglades National Park (Figure 1). We conducted this study in wet prairies and sloughs predominated by spikerush *Eleocharis* spp., common habitats in the Florida Everglades used by fishes and wading birds (Loftus and Eklund 1994; Jordan et al. 1997). During this study, water depth at our sites ranged from 45 to 85 cm and temperature from 15°C to 25°C (Table 1). We believed that our evaluation of airboat electrofishing in this area would be relevant to other freshwater marsh and littoral habitats predominated by emergent macrophytes with similar architecture.

Sampling protocol.—To estimate fish density and electrofishing CPUE at the 11 sites, we established two plots (≥1 ha) of uniform habitat at each site, and in each plot set one 0.1-ha block net and conducted three 5-min electrofishing transects in the vicinity of the net. Because of the proximity of the two plots within each site, we did not feel they constituted independent replicates. Therefore, we calculated mean fish density and CPUE (number captured per 5-min transect) for each site from the two block-net samples (one per plot) and six electrofishing transects (three per plot), yielding 11 paired density and CPUE estimates for our analyses.

The block nets (0.64 cm mesh) enclosed a square 0.1-ha area of marsh. We deployed these nets from a johnboat; one person pulled the boat while wading through the marsh as a second person within the boat deployed the net. We then added rotenone to the enclosed area at a concentration of 1 L per 100 m^3, based on the experience of researchers working in similar habitats (Jon Fury, Florida Game and Freshwater Fish Commission, personal communication). This is a greater concentration of rotenone than Davies and Shelton (1983) prescribed, but it has proven to be necessary in these marshes where large quantities of suspended material are usually present. We cleared fishes from the block nets for 2d when average water temperature exceeded 19°C and for 3 d when 19°C or less. Captured fish were identified to species and measured to the nearest 1 mm SL. To minimize fish mortality outside the net, we applied potassium permanganate, using standard methods (Davies and Shelton 1983), to the area surrounding each net immediately following rotenone additions and then inside each net after the final fish clearance.

We estimated our clearance efficiency from a subset of eight net sets. For each of these sets, four or five fin-clipped fish were added to the nets at least 0.5 h before rotenone was applied. These fish were collected by electrofishing outside the net and were allowed to fully recover before being placed in the block nets. We then noted the proportion of fin-clipped fish recovered after normal rotenone application and fish clearance.

Our electrofishing apparatus used a two-anode–one-cathode setup with a Smith-Root GPP 9.0 model control box. We suspended the two anodes 2 m apart and 2.5 m in front of the boat and used

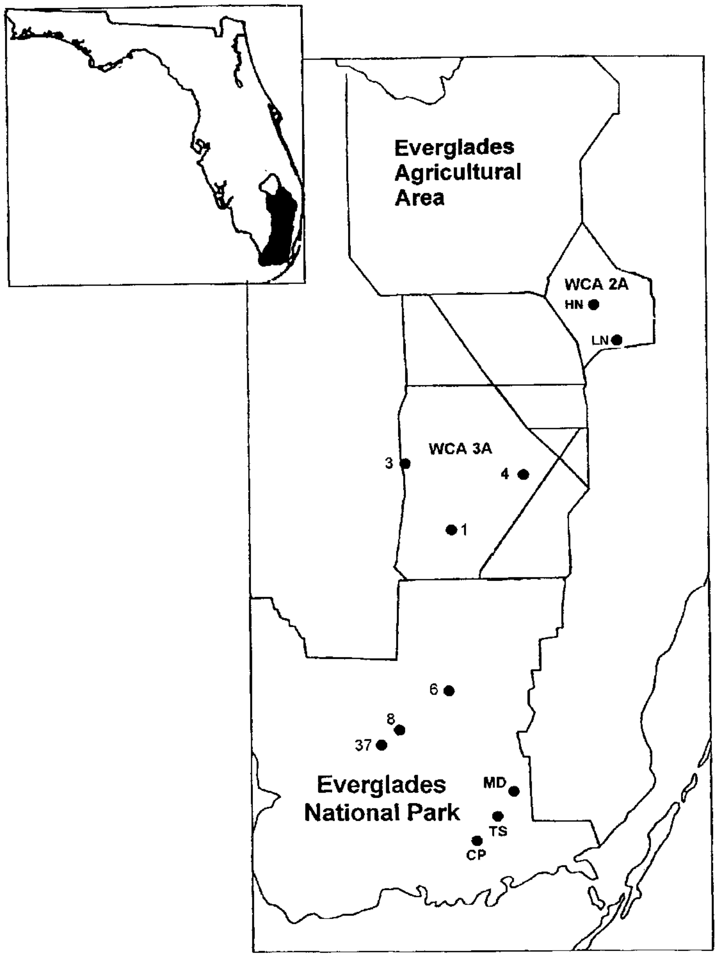

FIGURE 1.—Map of the central and southern portions of the Florida Everglades, including five sites in Water Conservation Area-2A (WCA-2A) and WCA-3A, and six sites in Everglades National Park; the 11 sites were sampled with airboat electrofishing and block nets from November 1997 to February 1998.

the hull of the airboat for the cathode. The two anodes were aluminum rings (0.5 m diameter) equipped with 10 dropper cables, each 20 cm long with a diameter of 0.64 cm. We used pulsed DC, generally at either 60 or 120 Hz, depending on which produced the appropriate amperage (see below), and measured water depth, temperature, and conductivity before the first electrofishing transect at a plot.

To improve our sampling consistency, we standardized electrofishing power at 1,500 W (wattage = voltage × amperage) over different temperature and conductivity conditions using the methods described by Burkhardt and Gutreuter (1995). From preliminary surveys, we determined that our effectiveness was greatest at a power of 1,500 W, assuming fish had a conductivity of 150 μS/cm (Burkhardt and Gutreuter 1995). We then selected the voltage and amperage needed to achieve this power level (amperage was fine-tuned with the peak voltage rheostat) for the specific water temperature and conductivity (YSI model 33 conductivity meter) levels measured at each site. Variation in temperature and conductivity was minimal between the two plots within a site, and all transects within a site were conducted at the same voltage and pulse settings.

We conducted all electrofishing transects between 0730 and 1700 h. Each transect was separated by a 50-m buffer and covered approximately 150–250 m of marsh; the airboat was run at idle speed (~4–8 km/h). We found fish avoidance of the current field to be somewhat problematic in these shallow marshes, so we manually switched

TABLE 1.—Habitat characteristics for the 11 sites in the Florida Everglades sampled with block nets and airboat electrofishing from November 1997 through December 1998. Water depth, temperature, and conductivity were measured directly during this study. Measurements of mean stem density and floating-mat volume (includes periphyton and the macrophytes *Bacopa caroliniana* and *Utricularia* spp.) are from concurrent throw-trap studies (J. Trexler and F. Jordan, unpublished data) conducted in the vicinity of our sites (methods in Jordan et al. 1997; Busch et al. 1998); NA = data not available because throw trap samples were not taken from these sites.

Location[a]	Site[b]	Water depth (cm)	Temperature (°C)	Conductivity (μS/cm)	Emergent stems/m^2	Floating mat (mL/m^2)
WCA-2A	HN	45	22.5	950	NA	NA
WCA-2A	LN	85	19.5	900	NA	NA
WCA-3A	3	70	21.5	255	182	1,416
WCA-3A	1	80	24	318	40	4,427
WCA-3A	4	87	23	325	46	3,846
Shark River Slough	6	54	24	400	130	1,962
Shark River Slough	8	57	25	415	185	2,371
Shark River Slough	37	57	19	395	178	932
Taylor Slough	MD	56	18	250	77	1,537
Taylor Slough	TS	58	15	225	90	993
Taylor Slough	CP	51	19	203	75	1,144

[a] WCA = Water Conservation Area.
[b] See Figure 1 for site locations.

the current on and off with a pedal switch during each transect (5 min pedal time) to minimize the number of fish avoiding the current field. One person operated the pedal and dipnetted the fish while the other operated the boat. Captured fish were identified to species, measured to the nearest 1 mm SL, maintained in a holding tank until completely recovered, and then released.

Data for emergent-stem density and floating-mat volume (includes periphyton and the macrophytes *Bacopa caroliniana* and *Utricularia* spp.) were gathered during concurrent throw trap studies (J. Trexler, F. Jordan, O. Bass, unpublished data) conducted in the vicinity of our sites (see Jordan et al. 1997 and Busch et al. 1998 for methodology).

Data analysis.—We limited our analyses to fish 8 cm SL or longer. Linear regression was used to test for a relationship between electrofishing CPUE (dependent variable) and block-net estimates of fish density (independent variable). Although the independent variable, fish density, is an estimate and has error associated with it, we believe standard (model I) linear regression is the appropriate statistical analysis. Error associated with an independent variable can bias linear regression results; however, standard linear regression usually provides a more conservative test of the null hypothesis than model II (geometric mean) regression. Sokal and Rohlf (1995) suggest that where a direct causal relationship exists between the dependent and independent variable (e.g., CPUE and fish density), standard linear regression should be performed, even if the independent variable has error associated with it. We also used linear regression to test for relationships between both CPUE and dry weight per unit effort (DWPUE; g/5 min) with block-net estimates of fish biomass in grams dry weight per 0.1 ha (g dwt/0.1 ha). Dry weight was estimated through published length to weight regressions (Kushlan et al. 1986). To comply with the normality assumption of linear regression, we log-transformed CPUE and biomass data prior to all analyses. We used the statistics described by Belsley et al. (1980) to check for observations that were unduly influential to the model predictions (Dffits) and estimates of the *y*-intercept (Ydfbeta) or slope (Sdfbeta) for all regressions (Influence option, Proc Reg, SAS Institute 1990). Observations with a Dffits, Ydfbeta or Sdfbeta greater than 2 were considered unduly influential to the regression analysis (Belsley et al. 1980).

We compared estimates of fish species richness (total number of species) from electrofishing and block netting. Species richness was determined for each method at each of the 11 sites. To account for differences in the number of individuals captured (which obviously affects the number of species captured), we used analysis of covariance (ANCOVA, type III sums of squares) to test for differences in species richness. The ANCOVA model included method (electrofishing or block net), the number of individuals sampled (covariate; $\log_{10}$-transformed), and their interaction. Species composition from electrofishing and block netting was compared using Pearson's goodness of fit chi-square analysis.

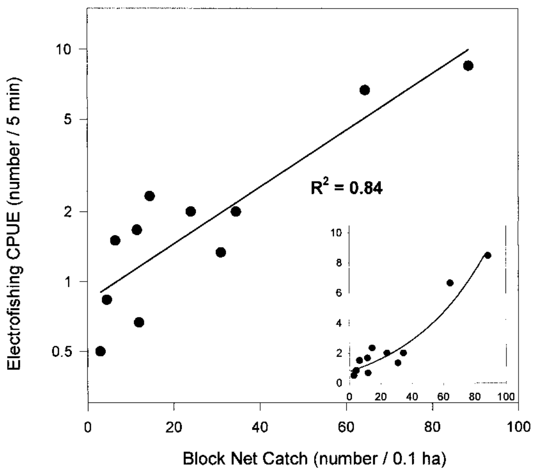

FIGURE 2.—Relationships between electrofishing catch per unit effort (CPUE; number/5 min; note axis is on a log scale) and fish density (number/0.1 ha) estimated from block nets. Data are from 11 sites in freshwater marshes of the Florida Everglades sampled from November 1997 through February 1998. The relationship depicted by the regression line is $\log_{10}$CPUE = 0.2456 + 0.0085(fish density). The insert in the lower right-hand corner depicts the same relationship with a linear *y*-axis.

For this analysis, we grouped fishes into seven categories: Florida gar *Lepisosteus platyrhincus,* yellow bullhead *Ameiurus natalis,* lake chubsucker *Erimyzon sucetta,* Seminole killifish *Fundulus seminolis,* largemouth bass, sunfishes (*Lepomis* spp.), and others.

To examine possible size biases, we used Pearson's goodness of fit chi-square analyses to compare electrofishing and block-net length distributions and ANCOVA to test whether relationships between CPUE ($\log_{10}$ + 1-transformed) and fish density differed among size-classes. Fishes were grouped into seven 2-cm size-classes for the length distribution comparison. Based on the results of this comparison, we grouped fish into two size-classes (8 to <12 cm and ≥12 cm) for the ANCOVA and tested for a significant interaction between size-class and fish density.

Finally, to examine whether environmental factors influenced electrofishing efficiency, we regressed residuals from the electrofishing CPUE–fish density regression against water depth, conductivity, emergent-stem density, and floating-mat volume. A significant relationship with any of these variables indicates that the variable needs to be included in the CPUE–fish density regression as an additional independent variable (or covariate). Based on these analyses, we conducted a multiple regression of CPUE ($\log_{10}$ + 1-transformed) with the independent variables fish density and emergent-stem density for comparison to our original CPUE–fish density regression.

TABLE 2.—Clearance efficiency for rotenone sampling in block nets, estimated from eight nets set at four sites within freshwater marshes of the Florida Everglades.

Site	Plot	Fish/0.1 ha	% clearance
Shark River Slough			
37	A	136	75
37	B	46	50
6	A	10	100
6	B	14	100
8	A	9	75
8	B	20	75
Taylor Slough			
CP	A	5	100
CP	B	1	25

Results

Airboat electrofishing CPUE was positively related to block-net estimates of fish density ($F_{1,\,9}$ = 45.97, $P \leq 0.0001$, $R^2 = 0.84$; Figure 2), suggesting that a greater $\log_{10}$CPUE is a reliable indicator of greater fish abundance. Fish density estimates for our 11 sites ranged from 3 to 88.5 fish/0.1 ha, and electrofishing CPUE ranged from 0.5 to 8.5 fish/5 min. The average clearance efficiency rate for block nets was 75% for all fish exceeding 8 cm SL. Clearance rate was fairly variable, ranging from 25% to 100% (Table 2). Site LN in WCA-2A and one plot in site 37 in Shark River Slough had substantially greater fish density than all others locations (LN = 64.5; site 37, plot A = 136 fish/0.1 ha), but no site unduly influenced the model predictions (Dffits <2), estimated *y*-intercept (Ydfbeta <2), or slope (Sdfbeta <2). Additionally, with these high data points removed, the relationship between CPUE and fish density was still positive and significant ($F_{1,\,8} = 9.56$, $P = 0.015$, $R^2 = 0.54$). Electrofishing DWPUE and biomass were not significantly related ($F_{1,\,9} = 2.95$, $P = 0.12$, $R^2 = 0.25$), but electrofishing CPUE was significantly related to biomass ($F_{1,\,9} = 6.82$, $P = 0.028$, $R^2 = 0.43$). No site unduly influenced the CPUE–biomass regression predictions (Dffits <2), estimated *y*-intercept (Ydfbeta <2), or slope (Sdfbeta <2).

Airboat electrofishing and block netting both captured 15 species, even though the total catch from block netting (589) was far greater than that for electrofishing (169; Table 3). The ANCOVA

TABLE 3.—Catch data from airboat electrofishing and block-net sampling in the Florida Everglades. Data are from 11 sites in *Eleocharis*-dominated wet prairies and sloughs sampled from November 1997 through February 1998.

		Total number captured	
Scientific name	Common name	Block net	Electro-fishing
Lepisosteus platyrhincus	Florida gar	17	30
Amia calva	Bowfin	4	6
Esox americanus	Redfin pickerel	1	1
Esox niger	Chain pickerel	8	0
Erimyzon sucetta	Lake chubsucker	110	44
Ameiurus natalis	Yellow bullhead	68	5
Clarias batrachus	Walking catfish	0	2
Fundulus seminolis	Seminole killifish	80	3
Belonesox belizanus	Pike killifish	1	0
Centropomus undecimalis	Common snook	0	1
Micropterus salmoides	Largemouth bass	30	29
Lepomis gulosus	Warmouth	50	10
Lepomis punctatus	Spotted sunfish	90	9
Lepomis macrochirus	Bluegill	13	5
Lepomis microlophus	Redear sunfish	70	15
Cichlasoma urophthalmus	Mayan cichlid	42	4
Oreochromis aureus	Blue tilapia	5	5
Total		589	169

model explained a significant amount of variation in species richness ($F_{3,\,18}$ = 18.86, $P \leq 0.0001$, R^2 = 0.76), and the slope of the relationship between species richness and the number of individuals sampled did not vary significantly between the two methods ($F_{1,\,18}$ = 2.96, P = 0.103). Species richness was significantly related to the number of

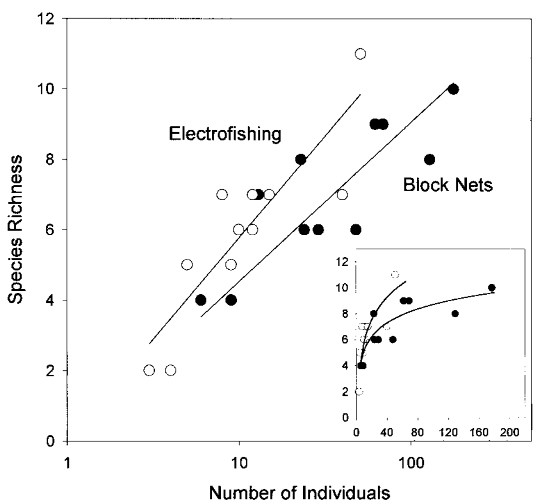

FIGURE 3.—The relationship between estimates of species richness and the number of individuals sampled (note *x*-axis is on a log scale) by airboat electrofishing (open circles) and block nets (filled circles) from 11 sites in freshwater marshes of the Florida Everglades. The insert in the lower right-hand corner depicts the same relationship with a linear *x*-axis.

individuals sampled ($F_{1,\,18}$ = 52.06, P = 0.0001), but species richness estimates from electrofishing and block netting did not differ ($F_{1,18}$ = 0.9, P = 0.36; Figure 3).

Species composition differed significantly between the block-net and electrofishing samples ($\chi_6{}^2$ = 219.9, $P \leq 0.001$; Figure 4). Yellow bullheads, Seminole killifish, and sunfishes composed a greater proportion of the block-net catch than the electrofishing catch (Figure 4). On the other hand, Florida gars and largemouth bass composed a greater proportion of the electrofishing catch than the block-net catch (Figure 4). Length distributions from the block-net and electrofishing samples also differed significantly ($\chi_7{}^2$ = 179.2, $P \leq$ 0.001), with electrofishing length frequency skewed toward larger size-classes (Figure 5).

Although length frequency from airboat electrofishing was skewed toward large size-classes, the relationship between CPUE and fish density for the 8–12-cm size-class was positive and significant ($F_{1,\,9}$ = 33.019, P = 0.0003, R^2 = 0.79; Figure 6). Similarly, electrofishing CPUE was positively related to fish density for the size-class 12 cm or longer ($F_{1,\,9}$ = 5.510, P = 0.044, R^2 = 0.38; Figure 6). No site unduly influenced the model predictions (Dffits <2), estimated *y*-intercept (Ydfbeta <2), or slope (Sdfbeta <2) in the regressions for either size-class. Mean CPUE differed significantly between size-classes ($F_{1,\,18}$ = 11.56, P = 0.0032), but the slope of the relation-

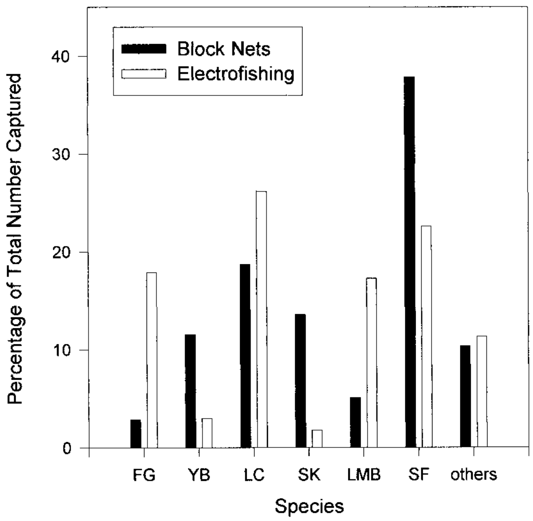

FIGURE 4.—Species composition from concurrent electrofishing and block-net samples collected from 11 sites in freshwater marshes of the Florida Everglades. Shown are the percentages of the total catch for Florida gars (FG), yellow bullheads (YB), lake chubsuckers (LC), Seminole killifish (SK), largemouth bass (LMB), sunfishes (SF), and other fish species (see Table 3).

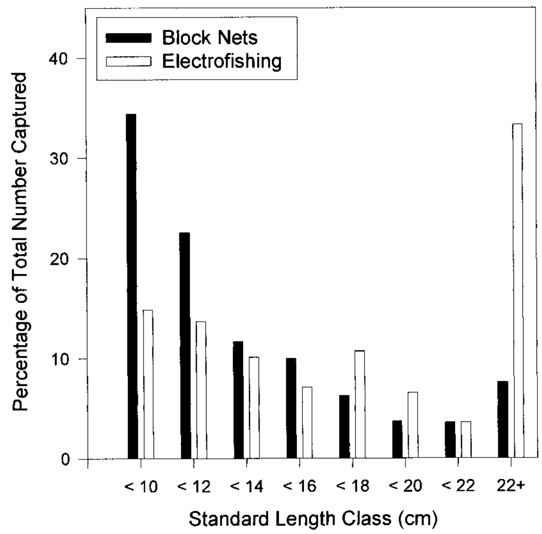

FIGURE 5.—Length-frequency (standard length, SL) distribution from electrofishing (open bars) and block-net samples (filled bars) from 11 sites in freshwater marshes of the Florida Everglades. Fish are grouped in 2-cm length-classes.

ship between electrofishing CPUE and block-net estimates of fish density did not differ significantly between size-classes ($F_{1,18} = 0.01$, $P = 0.94$; Figure 6).

Residuals from the electrofishing CPUE–fish density regression were positively related to emergent-stem density ($F_{1,7} = 14.84$, $P = 0.006$, $R^2 = 0.67$; Figure 7A), whereas no relationship was apparent with water depth, conductivity, or floating-mat volume ($F_{1,7 \text{ or } 9} < 1.50$, $P > 0.10$, $R^2 < 0.15$; Figure 7B–D). The pattern of residuals with stem density suggests airboat electrofishing is somewhat less effective in sparsely vegetated habitats than in habitats with greater stem densities (Figure 7A). The addition of stem density as a second independent variable, improved the relationship between electrofishing CPUE and block-net estimates of fish density ($F_{1,6} = 96.02$, $P = 0.0001$, $R^2 = 0.96$) and revealed a positive relationship between CPUE and stem density ($F_{1,6} = 22.14$, $P = 0.0033$). This suggests that emergent-stem density may be an important habitat variable to include in statistical analyses of airboat electrofishing CPUE (i.e., as a covariate).

Discussion

Our study demonstrates that airboat electrofishing is an effective method for sampling large fishes (≥8 cm SL) in shallow vegetated habitats. Positive relationships between electrofishing $\log_{10}$CPUE and both fish density (number/0.1 ha) and biomass (g dwt/0.1 ha) indicate that $\log_{10}$CPUE is a useful index of fish abundance. This is encouraging be-

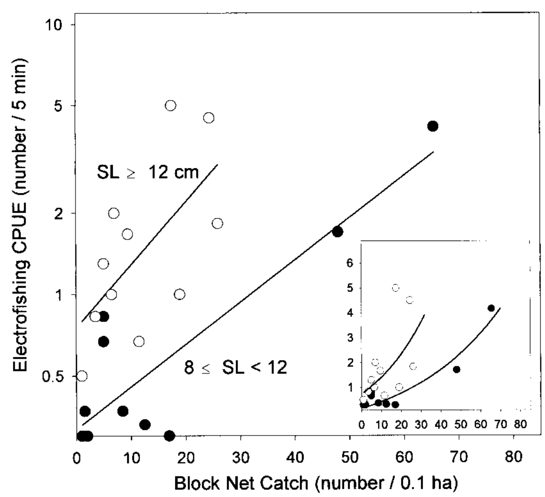

FIGURE 6.—A comparison of electrofishing catch per unit effort (CPUE; number/5 min; note axis is on a log scale) and fish density (number/0.1 ha) estimated from block nets for two length-classes (8 ≤ standard length, SL < 12 cm = filled circles, SL ≥ 12 = open circles) of fishes from 11 sites in freshwater marshes of the Florida Everglades. The insert in the lower right-hand corner depicts the same relationship with a linear *y*-axis.

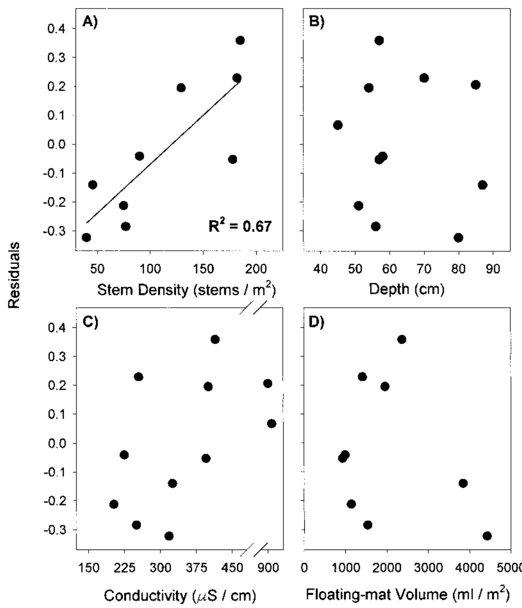

FIGURE 7.—Relationship between the residuals from the electrofishing catch-per-unit-effort–fish density regression (see Figure 2) and **(A)** emergent-stem density, **(B)** water depth, **(C)** conductivity, and **(D)** floating-mat volume.

cause electrofishing CPUE data are frequently used in statistical analyses, including studies conducted in vegetated habitats, and a positive relationship between CPUE and fish abundance is assumed (Killgore et al. 1989; Gelwick and Matthews 1990; Miranda and Pugh 1997). Airboat electrofishing also provided useful data on species richness, although the number of individuals sampled is critical to this metric. These results suggest that it is appropriate to use airboat electrofishing $\log_{10}$CPUE and species richness data in statistical analyses such as habitat-use comparisons or assessments of population and community-level trends through time.

We focused on determining whether airboat electrofishing CPUE is a useful index of fish abundance, rather than developing an empirical model predicting fish density from electrofishing CPUE. Although models have been developed to predict largemouth bass abundance in ponds from electrofishing CPUE (Coble 1992; Edwards et al. 1997), we believe predictive equations should be based on a greater number of samples dispersed over a wider range of fish densities than was possible in our study. We found fish densities exceeding 40 fish/0.1 ha at only two sites during this study. Turner et al. (in press) noted that standing stock of fishes in freshwater marshes of the Everglades are low compared to similar habitats in other systems, a fact reflected in the low fish densities observed in our study. Development of accurate predictive models also will require better knowledge of catchability for airboat electrofishing (Arreguín-Sánchez 1996). The catchability coefficient, q, has traditionally been defined as the slope in the linear relationship between CPUE and fish abundance (CPUE $= q$N, where N and CPUE can be expressed in terms of density or biomass). In reality, however, the relationship between catchability and fish abundance is often inverse and nonlinear, facts critical to studies assessing population dynamics using catch data from commercial and recreational fisheries (Peterman and Steer 1981; Peterman et al. 1985; Arreguín-Sánchez 1996).

Log-transforming CPUE suggests an exponential relationship with fish density; however, we used this transformation to comply with the normality assumption of linear regression, not because we believed the true analytical relationship between CPUE and fish density is exponential.

Because we had few observations from high density localities, our data are not sufficient to determine the true analytical relationship between CPUE and fish density, which may be linear or sigmoidal rather than exponential. Nevertheless, other researchers have suggested that abundance indices using CPUE data should be based on log-transformed CPUE to account for catchability variation among fishing vessels (Gulland 1956; Robson 1966; Kimura 1981) or for indices constructed from multiple methods (Kimura 1988). Given the results of our study and the fact that many biotic and abiotic factors varying in space and time could influence catchability of airboat electrofishing (Zalewski and Cowx 1990; Harvey and Cowx 1996), log-transformed CPUE may be a more conservative and reliable index of fish abundance than untransformed CPUE. Electrofishing CPUE data are frequently log-transformed to normalize residual errors before statistical analyses, so our suggestion is compatible with common research practices.

Airboat electrofishing appears to be an effective sampling method in shallow vegetated habitats, but appears to have species-specific and size-related biases. In our study, length frequency data from airboat electrofishing was skewed toward large size-classes. This is consistent with several studies demonstrating that susceptibility to electrofishing increases with body size (reviewed by Reynolds 1983; Zalewski and Cowx 1990). Although $\log_{10}$CPUE appears to reflect fish abundance across the size range we examined (≥8 cm SL), length-frequency data from electrofishing should be interpreted with caution. Species-composition data from airboat electrofishing also is likely to be biased because fishes differ in susceptibility to electrofishing because of behavioral and physiological factors (Reynolds 1983; Zalewski and Cowx 1990). In our study, the relative abundance of yellow bullheads was less in our electrofishing samples than in our block-net samples. The epibenthic distribution of yellow bullheads probably limited our ability to detect them. The relative abundances of Seminole killifish and sunfishes were also less for electrofishing, but the causes for these discrepancies are less clear. As with length-frequency data, species-composition data from electrofishing should be interpreted with caution since unknown biases may exist.

Several environmental factors can influence the effectiveness of electrofishing. Water conductivity and temperature affect the transfer of power (wattage) from water to fish (Kolz and Reynolds 1990; Burkhardt and Gutreuter 1995). Burkhardt and Gutreuter (1995) described a method to standardize electrofishing power for various levels of conductivity and temperature. We used this method and found no pattern in the residuals from the CPUE–fish density regression, with respect to conductivity. This suggests that the standardization of power was effective for the range of temperature and conductivity we encountered.

Other environmental factors, such as water depth, vegetation density, and floating-mat volume can affect detection and capture of stunned fish. Of these factors, only emergent-stem density appeared to influence electrofishing effectiveness during our study. Our data suggest airboat electrofishing was less effective in sparsely vegetated habitats. When emergent-stem density is low, fish may be better able to detect and flee from the approaching airboat. An alternative explanation is that the effectiveness of block netting may have been inversely related to stem density. Although we cannot distinguish between these alternatives, airboat electrofishing creates substantial noise and we have observed fish fleeing from the airboat in sparsely vegetated habitats. We suggest that researchers sample emergent-stem density when gathering airboat electrofishing data and use stem density as a covariate in statistical analyses.

Although a substantial literature exists describing the effectiveness of various methods used to sample small fishes in shallow, vegetated habitats (see Jordan et al. 1997; Rozas and Minello 1997), methods for sampling large fishes in these habitats have not been perfected. Marsh and wetland habitats such as the Florida Everglades have been and continue to be altered by human activity (Davis et al. 1994). Many questions regarding the role of fishes in the trophic and community ecology of these habitats remain unanswered, in part because of the difficulty of obtaining accurate field data on abundance and composition of fishes (Chick et al. 1992; Chick and McIvor 1994; Loftus and Eklund 1994; Rozas and Minello 1997). We suggest that airboat electrofishing is an effective method for sampling large fishes in shallow vegetated habitats, and log-transformed CPUE is suitable for assessing abundance patterns over large spatial scales and through time. Nevertheless, airboat electrofishing size-frequency and species-composition data are likely to be biased. Therefore, we caution that accurate descriptions of the abundance, size distribution, and species composition for the entire community of fishes using shallow, vegetated habitats requires a combination of methods (e.g., electrofishing, throw trapping, and block netting) and sampling over multiple spatial and temporal scales.

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